Understanding Santa Ana Winds and Fire Progression

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Background: What are Santa Ana Winds?

- A relatively ephemeral weather phenomenon, lasting from a few hours to 2-3 days[1]
- Santa Ana season stretches from fall to spring
- Incorporates hot, high-speed offshore winds with very low relative humidity
- Affects the coastal southern California region, typically associated with driving many wildfires to catastrophic size

Smoke from the 2007 California wildfires being pushed out over the Pacific Ocean by Santa Ana winds, as seen by NASA's Terra satellite

[1]*Raphael MN (2003). The Santa Ana Winds of California*. Earth Interactions *7(8):1-13.*

How are Santa Ana Winds quantitatively related to fire progression?

- Unknown!
  - Very little in the literature to suggest that we understand how Santa Ana winds directly affect fire progression rates
- Moritz et al. 2010
  - Showed that particularly large fires have a higher probability of occurring in areas of historically high fire risk (as indicated by an index derived from October Santa Ana events ’95-’03), but did not link specific Santa Ana events to specific fires
- There is no standard definition of what combination of weather parameter thresholds define a Santa Ana wind event
  - Most definitions are based on pressure gradient differences, but we found three that are based on widely available and easily detectable weather parameters

Santa Ana Criteria Used for Study

Source	ID	Wind Direction	Wind Speed	Relative Humidity
San Diego County	SA1	>345° and <115° true	>3.8 m/s	<30%
National Weather Service Red Flag Day Criteria	SA2	---	> 11.18 m/s sustained > 15.65 m/s frequent gusts	<15% for >6 hours
Sergius and Huntoon (1956)	SA3	0° to 90° true	≥8.93 m/s	<40% at 1630 PST

Study Outline

- Do burns occurring on days with Santa Ana wind conditions have a greater area than those that do not?
- How do Santa Ana definition parameters (relative humidity, wind speed, wind direction) relate to burn area per day?
- Are there other parameters (weather, topographic, fuels, etc.) that are better predictors of burn area per day?
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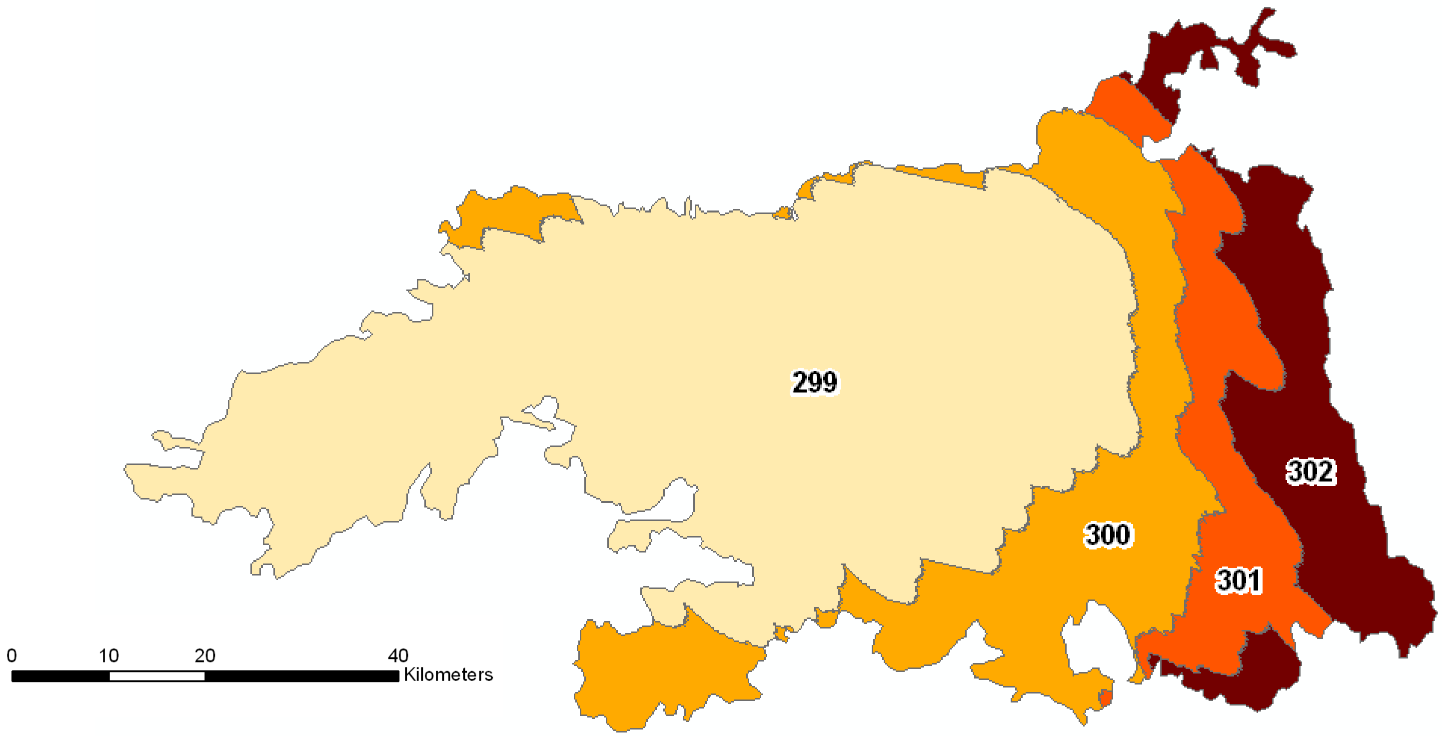
Datasets : Fire Progression Polygons

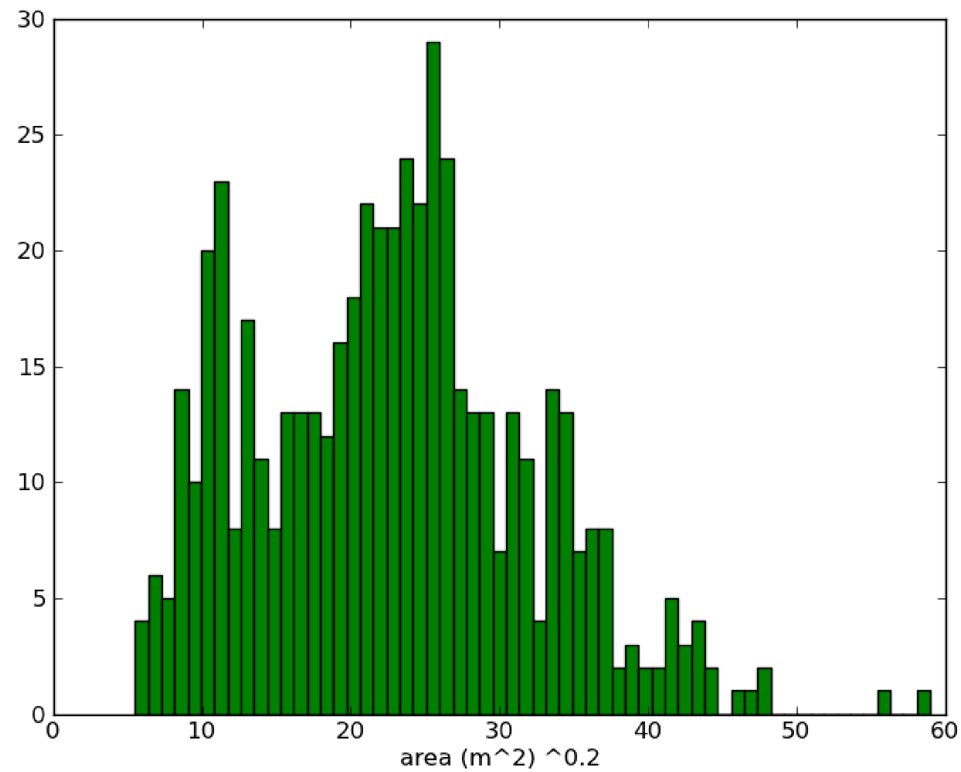
- MODIS-based, daily fire progression maps developed by Dr. Tatiana Loboda, University of Maryland
  - Model bounded by MTBS Landsat-derived fire perimeters
  - Burned area pooled by day and fire event



2003 Cedar Fire: >260,000 acres burned in 4 days

Datasets : Fire Progression Polygons

- This study used 528 total burn area polygons grouped by fire and date.
- The dataset comprises 163 distinct wildland fire incidents from 2001-2009 in southern California within 32.5 to 35.4° latitude and -116.0 to -120.6° longitude
- Individual fires in the dataset lasted anywhere from 1 to 44 days (mean 3.4 days).
- Polygon burn area was non-parametrically distributed with a mean of 2081 ± 5055 ha (median = 635 ha)
- The dataset was power transformed by 1/5 in order to approximate normality for the use of more powerful parametric tests

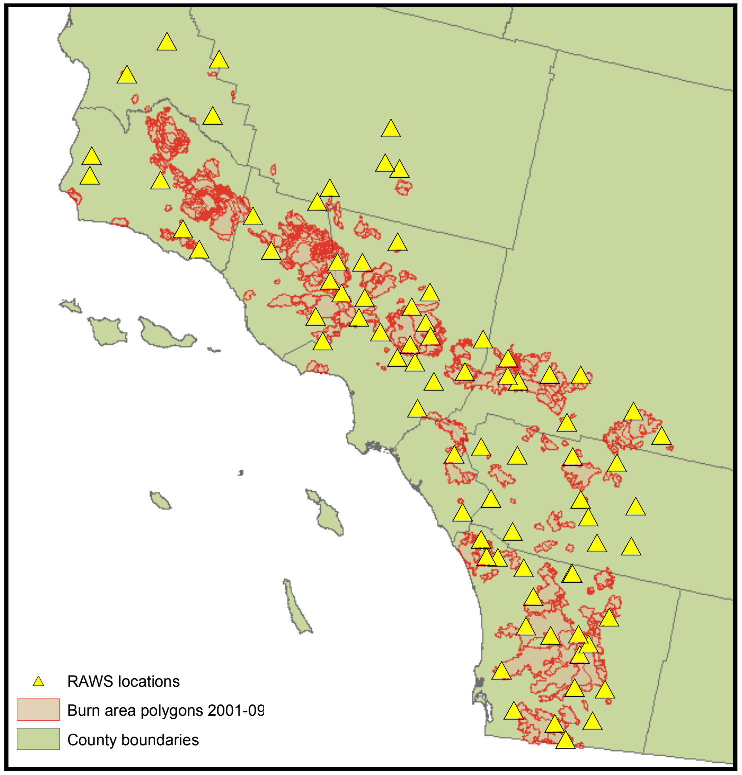


Datasets: RAWS

- **Remote Automated Weather Stations (RAWS)**
  – **RAWS** is an interagency network comprising 2,200 stations located throughout the United States. Data is compiled and distributed by the National Interagency Fire Center (NIFC) in Boise, Idaho.

- Advantages
  - High temporal (hourly) resolution
  - Over 20 standardized weather variables available
  - Extensive network (82 units within study area)

- Linking to fire progression dataset
  - Linked by shortest straight-line distance
  - The mean distance from a burn area polygon to its assigned RAWS station was 8.5 ± 6.4 km.



Methods: Detect Santa Ana events

Santa Ana events as detected by RAWS

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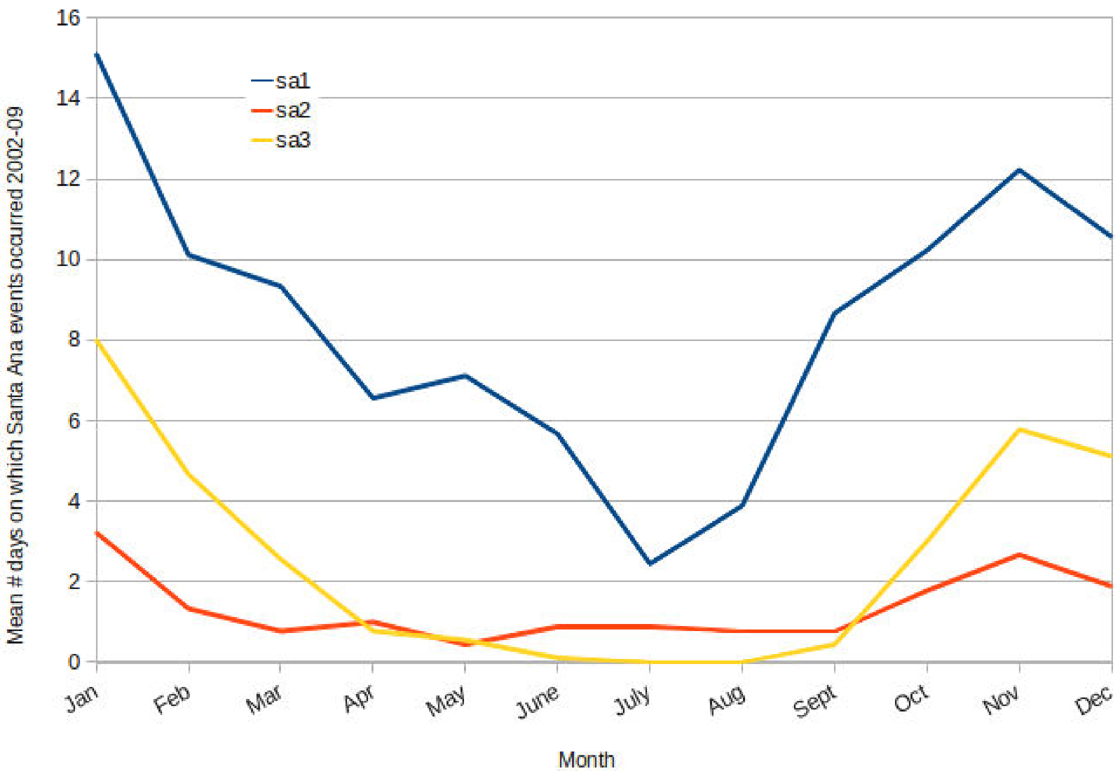
- Seasonal pattern compares well with Santa Ana events defined using mapped pressure gradients (Raphael 2003)
- Raphael found the # of Santa Ana events per month peaked at around 4 from November to January -> compares well sa2 & sa3
- This also illustrates that our sa1 criteria (San Diego County) is a much more lax definition than has been previously documented.



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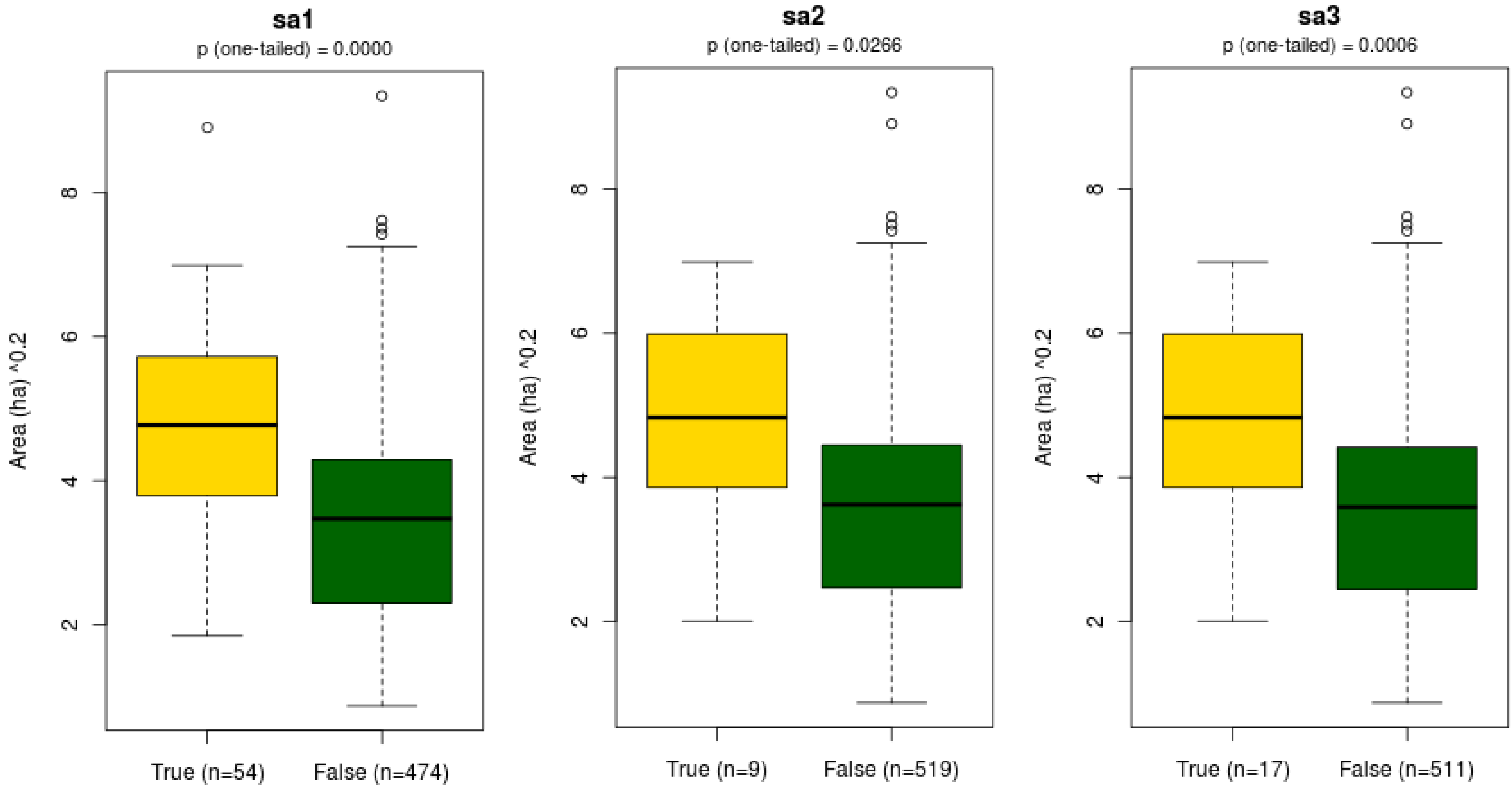

Non-transformed mean area:
True = 4,957 ha, False = 1,757 ha

2.8 x greater

Non-transformed mean area:
True = 4,700 ha, False = 2,039 ha

2.3 x greater

Non-transformed mean area:
True = 4,456 ha, False = 2,005 ha

2.2 x greater

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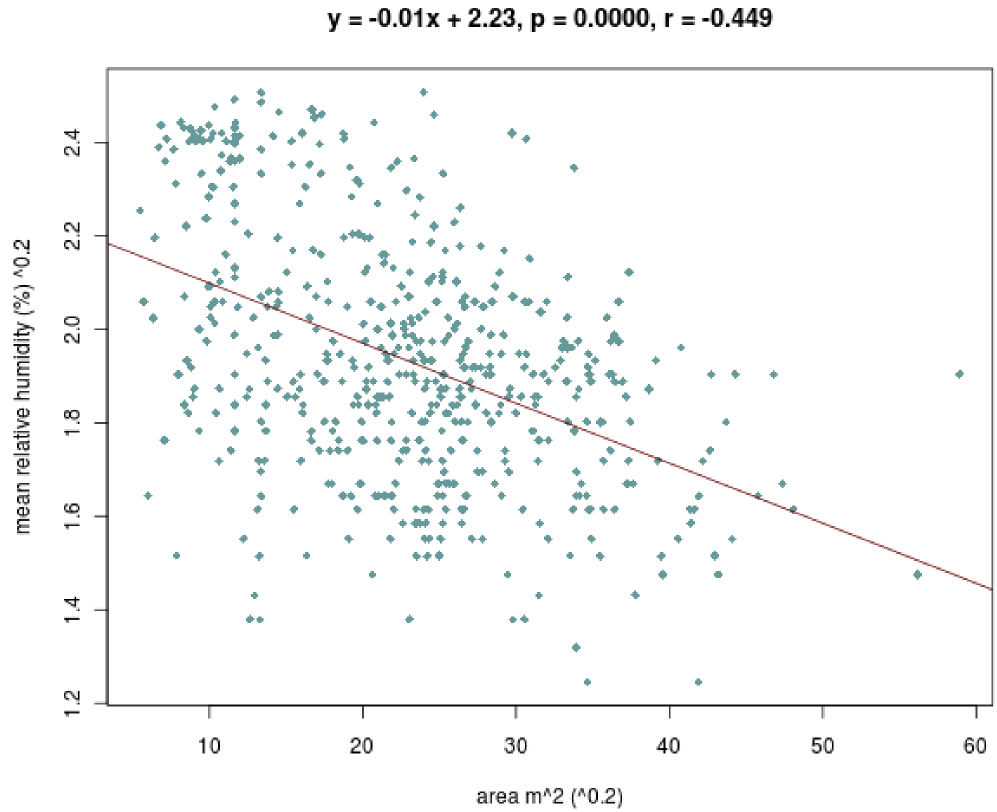
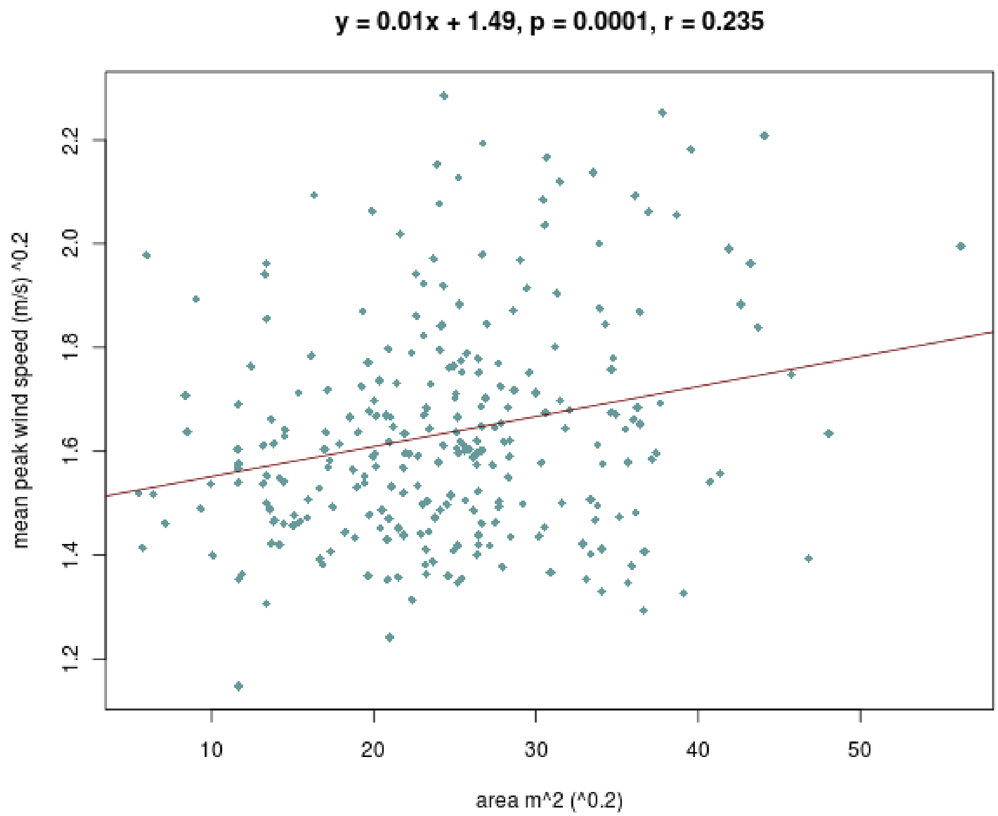
How do Santa Ana definition parameters relate to burn area per day?

- **Relative humidity**
  - As expected, relatively strong negative correlation
  - r = -0.449
  - Of the three variations we used (mean daily, min. daily, and PST 1630), mean daily is slightly stronger



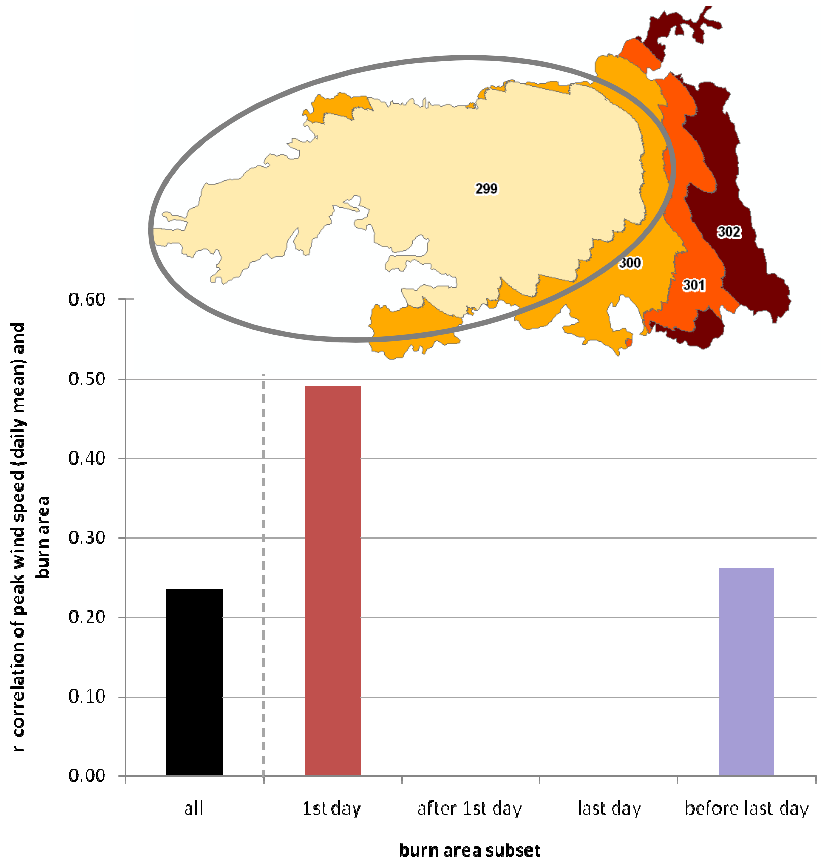
How do Santa Ana definition parameters relate to burn area per day?

- **Wind speed**
  - As expected, positive correlation
  - Of the three variations we used (mean, mean gust, mean peak), mean peak was the strongest
  - HOWEVER, correlation is unexpectedly weak:
    - Mean: not significant
    - Gust: r = 0.17
    - Peak: r = 0.24



How do Santa Ana definition parameters relate to burn area per day?

- **Wind speed** – examination of weak correlation:
  - Does strength of correlation change when looking at subsets of burn area based on duration and temporal position?
  - YES
    - Burn polygons that represent only the 1st day of a fire have a much higher correlation strength
      - Gust : r = 0.35
      - Peak: r = 0.49
    - This suggests that wind speed plays a key role in the establishment of a fire after ignition, but a very small role if any after established



How do Santa Ana definition parameters relate to burn area per day?

- **Wind Direction**
  - Since not a linear variable, the effects of wind direction on burn area were tested by comparison of means
  - The directions for which burn area was significantly greater align with those used to define Santa Ana winds

Wind Direction	p-value	Mean ha within (n)	Mean ha outside (n)
0 - 45°	**0.0042**	2583 (60)	2024 (467)
45 - 90°	**0.0000**	5989 (59)	1596 (468)
90 - 135°	0.2917	1242 (37)	2152 (490)
135 -180°	0.9982	768 (68)	2283 (459)
180 - 225°	0.9999	1421 (89)	2223 (438)
225 - 270°	0.8465	1672 (80)	2162 (447)
270 - 315°	0.8332	1462 (68)	2180 (459)
315 - 360°	**0.0286**	2154 (62)	2079 (465)

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Are there other parameters that can better predict burn area per day?

- Attempted to identify and run linear regression on any variable that could have an effect for which data was available
  - RAWS units collect an assortment of weather parameters:
    - 10-hour fuel moisture
    - Fuel temperature
    - Precipitation
    - Air temperature
    - Dew point
  - Additional spatially derived parameters we decided to look at:
    - Topographic slope (derived from DEM)
    - Fuel loading (from Fuel Characteristic Classification System, FCCS)
    - Wildfire front length (spatially derived)
    - Population density and housing unit density (from 2000 Census)

Are there other parameters that can better predict burn area per day?

- Summary
  - Not unexpected results:
    - 10-hour fuel moisture, dew point, and precipitation all had negative correlations, all weaker in strength than relative humidity
    - Fuel temperature and air temperature had weak positive correlations
    - Topographic slope had very weak positive correlation
    - Wildfire front length had a very strong positive correlation (only after the first day of multiday fires, as expected)
    - Fuel loading positively correlated with area, especially after the first day of multiday fires
  - Strange result:
    - Population density and housing unit density had relative strong (r ~ 0.35) *positive* correlation only for the first and last day of multi-day fires
      - Possible explanations:
        - » First day: Linked to anthropogenic causes of ignition in areas of higher population density?
        - » Last day: Active containment disrupts typical “petering out” natural fire progression?

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What suite of parameters best predicts burn area per day?

- Multivariate analysis – General Linear Model
  - Iterated through all possible combinations of weather, topographic, etc. variables
  - Included bimodal variables (1 = True, 0 = False):
    - Wind direction is NE
    - Burn day is 1^{st}
    - Burn day is last
    - Burn is part of multiday fire
    - Burn is coastal

What suite of parameters best predicts burn area per day?

- **GLM Results**

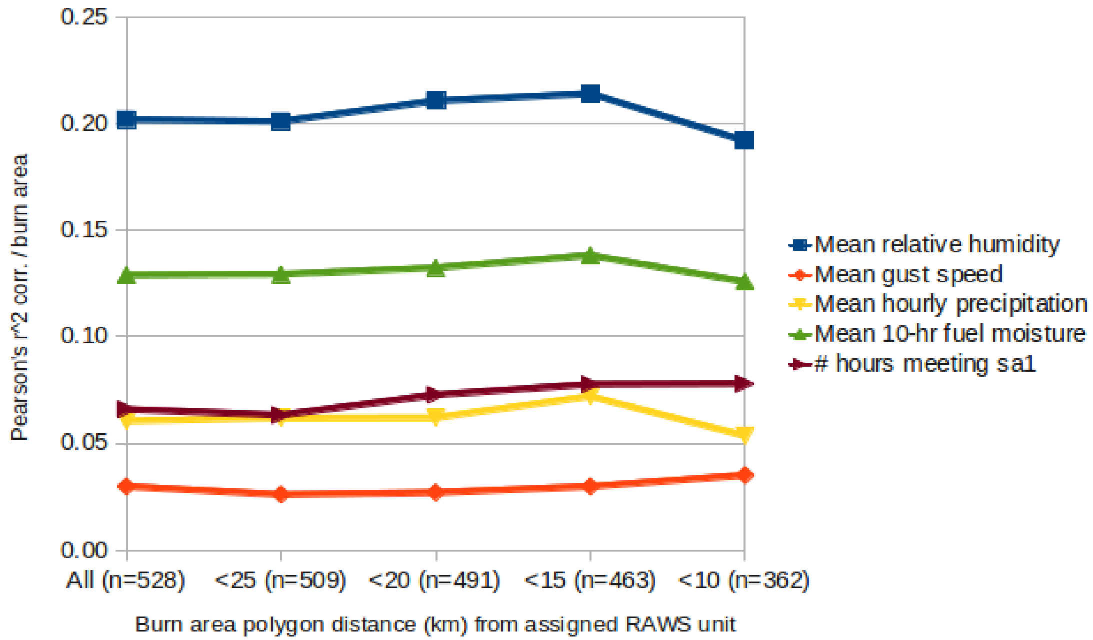
Parameter	Coefficient	p-value
Relative humidity (daily mean)	-8.89	< 0.001
Peak wind speed (mean of hourly)	4.62	< 0.05
Wildfire front (length)	2.16	< 0.001
Burn day is 1st	12.8	< 0.001
Burn day is last	-3.33	< 0.001
Intercept	21.9	< 0.001
r^2	**0.509**	

Discussion: Take Away Points

- **Three key points**
  - Area of burn polygons occurring under Santa Ana conditions is over twice as large as those occurring under non-Santa Ana conditions.
  - Of the three Santa Ana classification parameters (relative humidity, wind speed, wind direction), relative humidity is the most consistently strong correlated with burn area (negative) while wind speed is strongly correlated only on the first day of a fire.
  - No other weather variable was shown to be a consistently strong predictor of burn area. The suite of variables comprising the best fit generalized linear model for predicting burn area included relative humidity, peak wind speed, wildfire front length, and two day of fire event indicators (is first day of a fire event, is last day of a fire event).

Appendix: Limitations of RAWS

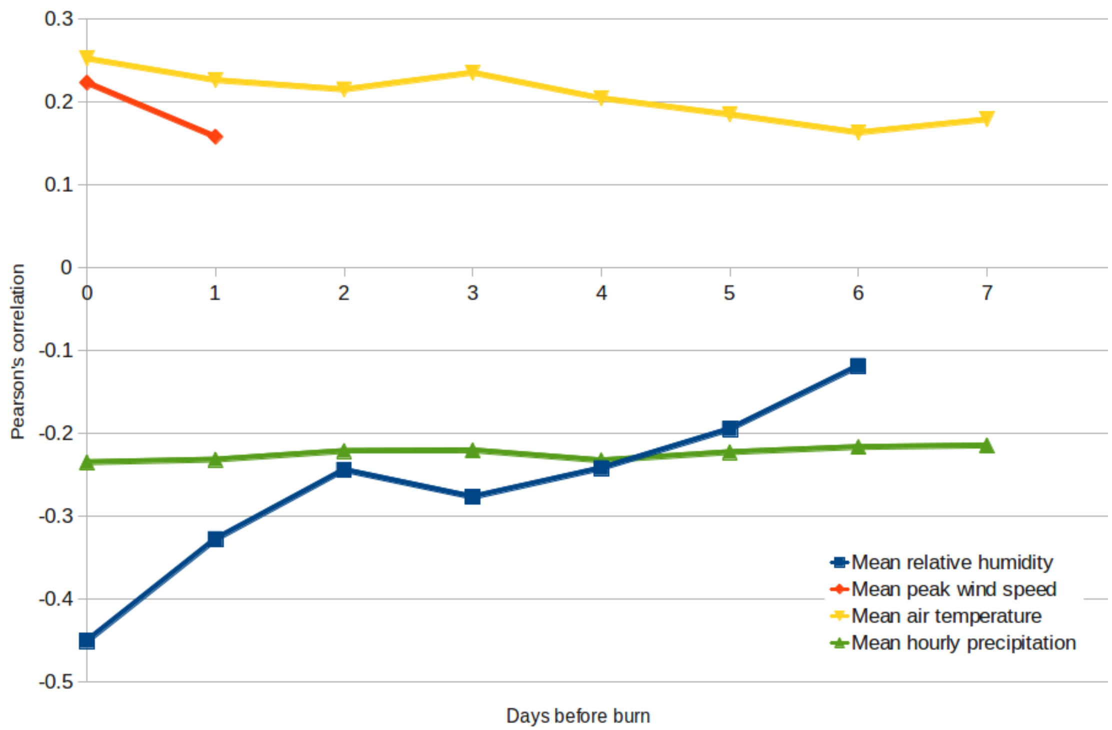
- RAWS unit data may misrepresent actual weather conditions for a burn area due to large distances separating the two



- There was at least one instance of a fire (Reche 2001) for which the 2nd closest RAWS unit (16.2 km vs. 16.1 km in opposite direction) likely more accurately reflected the local weather conditions (as evidenced by local weather and news reports)

Appendix: Time lag effects

- Strength of correlation with burned area decreased with number of days before burning for all weather variables (figure below shows 4 examples)
- Separately, total precipitation summed over 1-7 days prior to burn did not improve the strength of correlation with burn area versus day-of total precipitation (7-day sum: r=-0.193, p = 0.000).



Appendix: Independent Variables

Parameter	Units	Source	Stat. Param	Mean|med±std	Definition
relative humidity (daily mean)	%	RAWS	^0.2	32|25 ± 22	Mean of hourly mean relative humidity measurements
relative humidity (daily minimum)	%	RAWS	^0.2	19|13 ± 16	Min. of hourly mean relative humidity measurements
relative humidity (at 1630 PST)	%	RAWS	^0.2	25|20 ± 19	Relative humidity measurement taken at 1630 PST
wind speed (daily mean)	m/s	RAWS	^0.2	2.8|2.3 ± 2.4	Mean of hourly mean wind speed measurements
wind speed (daily max)	m/s	RAWS	^0.2	5.7|4.9 ± 3.8	Maximum of hourly mean wind speed measurements
gust (daily mean of hourly)	m/s	RAWS	^0.2	5.9|4.8 ± 4.0	Mean hourly of max. 3 sec.mean over 2 minute period
peak wind speed (daily mean of hourly peaks)	m/s	RAWS	^0.2	14 | 11 ± 11	Mean of hourly peak wind speed measurements
dew point (daily mean)	°F	RAWS	^1	43|44 ± 12	Mean of hourly mean dew point measurements
fuel temperature (daily mean)	°F	RAWS	^1	75|76 ± 10	Mean of hourly mean fuel temperature measurements
temperature (daily mean)	°F	RAWS	^1	72|74 ± 10	Mean of hourly mean air temperature measurements
precipitation accumulation (hourly mean)	in.	RAWS	^0.2	5.6|2.2 ± 7.4	Mean of hourly precip. accumulation measurements
10-hour fuel moisture (daily mean)	%	RAWS	^0.2	7.4|6.0 ± 5.3	Mean of hourly 10-hour fuel moisture MORE
# hours that met SA1 criteria	hr	RAWS	NP	2.3|0 ± 5.4	# hours in the day that meet criteria specified by SA1
2000 population density	p/mi^2	CENSUS	NP	47|3 ± 118	Mean US CENSUS 2000-derived population density
2000 housing unit density	h/mi	CENSUS	NP	16|2 ± 50	Mean US CENSUS 2000-derived housing unit dns.
Wildfire front (length)	km	Fire Prg.	NP	10|2 ± 18	Length of wildfire front at the start of the day
Slope	°	NED	None	19|19 ± 7	NED 1/3 arc second (10m)-derived slope
Fuel loading	tons/ac	FCCS	^0.2	42|43 ± 11	Area-weighted mean fuel loadings